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A STUDY OF THE NON-UNIFORMITY IN RUNNING RATES OF A CERTAIN TYPE OF TIME DELAY MECHANISM

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Abstract of Report
on a Study of the Non-Uniformity of the
Running Rates of a Certain Type of
Time Delay Mechanism

From a study of nearly 300 samples of a certain type of clock mechanism it was found that the period varies some 8% above and below the most popular value. The most important reasons for this variation are (1) the differences in geometrical dimensions of the verges, (2) the differences in the center to center spacing of verge and starwheel shafts, (3) the friction of the gear train which transmits the torque from the spring to the starwheel.

It was shown that shape or condition of shafts and bearing holes is relatively unimportant. Less important effects were also noted. All work described was carried out on the assumption that the mechanism is <u>not</u> being accelerated as a whole.

A Study of the Non-Uniformity of the Running Rates of a Certain Type of Time Delay Mechanism

I. INTRODUCTION.

A certain type of time delay mechanism is based upon the behaviour of an untuned verge driven by a toothed wheel, this wheel being the final element in a train of gears actuated by a coil spring. In two previous reports (these reports being on file in the library of Diamond Ordnance Fuze Laboratory) will be found a complete theoretical discussion of the effect of both dynamic and geometrical factors on the operation of this device.

The purpose of the work discussed in this report was to ascertain where possible, the reasons for the non-uniformity in behaviour of supposedly identical mechanisms. These studies refer only to the case where the mechanism as a whole is not being accelerated. The results reported in most cases deal with the nominal 1 second mechanism; that is, a mechanism whose running time is supposedly 1 sec. Approximately 300 such identical mechanisms were used in the tests, all of them heretofore being unused. These 300 mechanisms all came from the same factory run, as far as is known, and appear to the eye to be exact replicas, one of the other.

In order to describe the various observations accurately, Figure 1 shows a purely schematic diagram of the essential parts of the mechanism with the names used in describing the parts. We emphasize the fact that this is a schematic diagram.

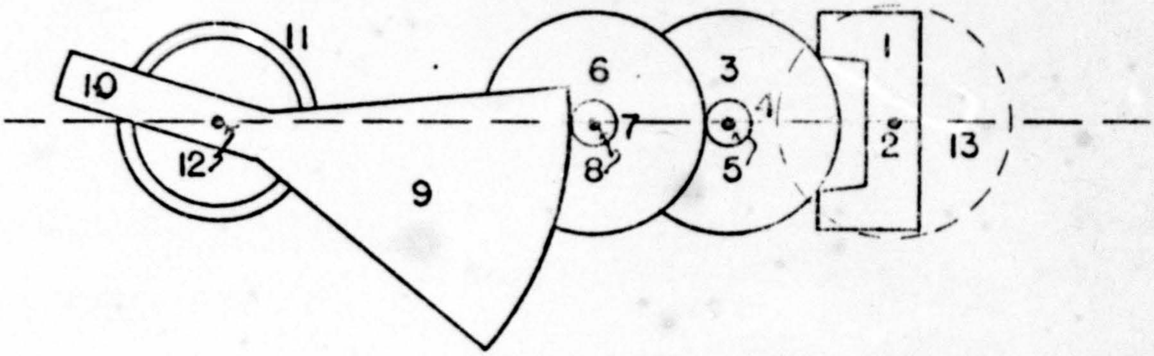


FIG. 1

1. verge
2. verge shaft
3. starwheel
4. starwheel pinion
5. starwheel shaft
6. intermediate gear
7. intermediate gear pinion
8. intermediate shaft
9. drive gear
10. cocking lever
11. coil spring
12. drive gear shaft
13. inertia disc.

Elements 3, 4, 6, 7, and 9 are all gears and are toothed. These teeth are not indicated.

The operation of the mechanism is as follows. Drive gear 9 is rotated counterclockwise as far as possible by the cocking lever 10. This winds the coil spring 11. During this operation, all other elements of the mechanism move. Then the cocking lever 10 is released, the spring 11 drives gear 9 in a clockwise rotation, this motion being transmitted to starwheel 3. As the starwheel rotates the two ends of verge 1 alternately collide with teeth on the starwheel 3. At each collision energy is removed from the system and a uniform average velocity is attained. The disc 13 increases the inertia of the verge, and helps determine the period. The period of the mechanism is the time required for the cocking lever to move from the "wound" position to the position at which it comes free of gear 6 and strikes a stop. The whole train shown schematically is cased between two circular plates roughly one inch in diameter. These two plates make up the case which provides the bearing holes for all shafts.

II. VARIATION IN PERIODS.

The actual period or delay time of a mechanism was measured in the following manner:

A scaler (Model 165 of Nuclear Instrument and Chemical Corporation) was modified by bringing out terminals for an external "count" switch. A pulse circuit consisting of a square wave generator and differentiating circuit was connected to the Geiger Muller input connector of the scaler as shown in Fig. 2.

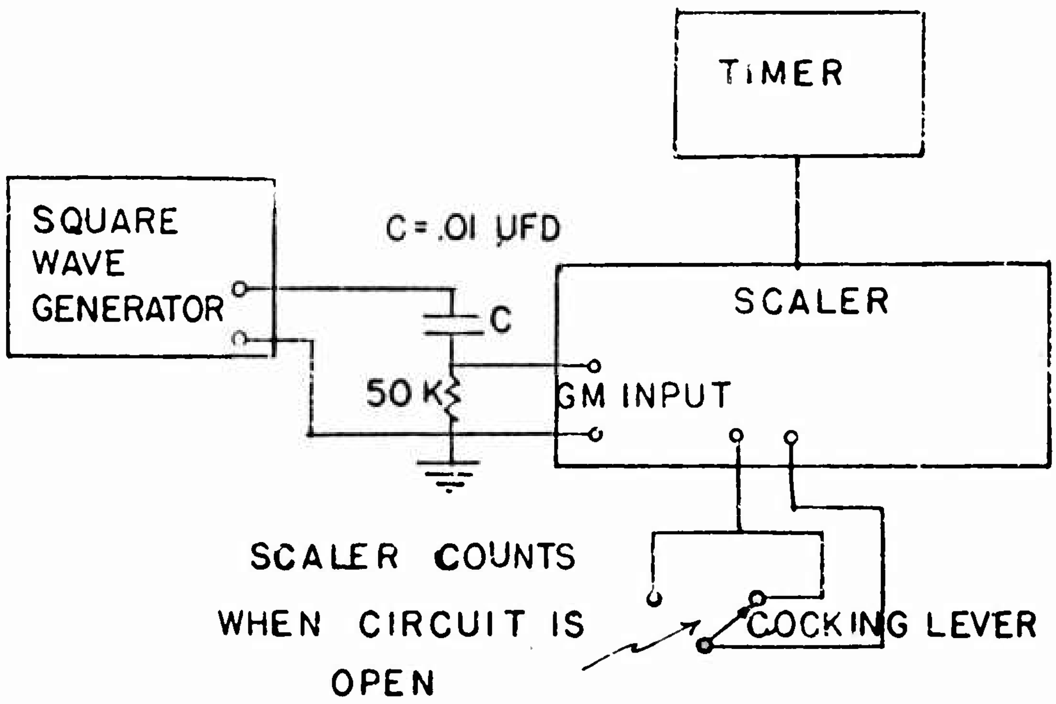


FIG. 2

Using the internal count switch of the scaler (external count switch closed) the frequency of the square wave generator was adjusted until the scaler was registering 100 counts per second. The count rate was checked from time to time during the series of measurements of the delay times of the mechanisms. In getting the delay time of a mechanism, the cocking lever acted as the blade of a single pole double pole switch, the scaler recording counts only while the "switch" was open. The delay times were recorded to the measured hundredth of a second but, obviously, a value obtained by a single measurement may be off by one hundredth of a second depending on the phase of the pulse input at the instant of release of the cocking lever of the mechanism. The cocking lever was released quickly by hand and it was found that while using a count rate of 100 per second, variations in release time did not appreciably affect measured delay times.

In these tests a sample of some 270 nominal one second mechanism was used. As far as we know, these mechanisms had not previously been run.

Each one in turn was run once and timed in the process. Then each was run and timed again, and then a third time. Finally each mechanism was run again and again until its period became constant, this equilibrium period being recorded. This gives four sets of data which were used to plot the curves shown as Figs. 3, 4, 5, and 6. The smooth curves were obtained by fitting the data to a normal frequency test relation curve, using the method of least squares. Ordinary statistical tests show that these distributions can legitimately be represented by normal frequency curves if the samples are large enough. In other words, if we had used a sample of 1000 or 2000 mechanisms the points would be expected to lie rather closely on the normal frequency curve.

The first conclusion we reach from Fig. 7 on which all these curves are plotted, is that generally speaking we find a shift of about .07 seconds in the running times or periods of the mechanisms as they wear in. This is probably to be expected, although the magnitude of this effect is somewhat surprising. One cannot ascribe this decrease in period to any particular portion of the mechanism. Small burrs on all the contact surfaces are being smoothed away, dust and dirt on these surfaces or perhaps in the coils of the spring is being loosened and thrown off.

A second striking observation is that the shape of the first and fourth curves is almost identical, particularly as to the maximum deviation in period from what we may call the mean time at the peak of the curve. For both cases, this maximum deviation is .07 sec. to .08 sec. on either side of the mean. By actual count, however (see Fig. 6), the number of mechanisms having a deviation of 0.05 or greater is only 39, or approximately 15% of the total. It should be noted that four or five of the original mechanisms were defective, and would have been rejected in a test inspection.

Some five weeks after the data discussed above was obtained, the periods of one hundred of the original mechanisms were measured again, with results indicated on Fig. 8. This sample being much smaller than the original, the resulting normal frequency curve is probably not as good a representation of the data as before. Considering this, and the fact that a difference of .01 sec. in period is not physically significant the curve of Fig. 8 can be said to agree closely with that of Fig. 6. We conclude that the periods of these clock mechanisms does not vary with time, at least during a few weeks. In other words, no rapid aging process is present.

Throughout our experimentation one phenomenon was observed to be present always. A mechanism having been "run in" was laid aside for a few hours or a few days. When run again and timed, the first reading was always high, with the second and perhaps the third decreasing to a constant value. Exceptions to this behaviour were very few in number, compared to the hundreds of times such behaviour was observed. The decrease in time noted during this process varied from one mechanism to another but generally did not exceed .02, although some few cases were noted in which a decrease of .05 sec. occurred. No explanation for this phenomenon is known although it could possibly be due in part to an aging process of the contact surfaces of verge, gears, and spring.

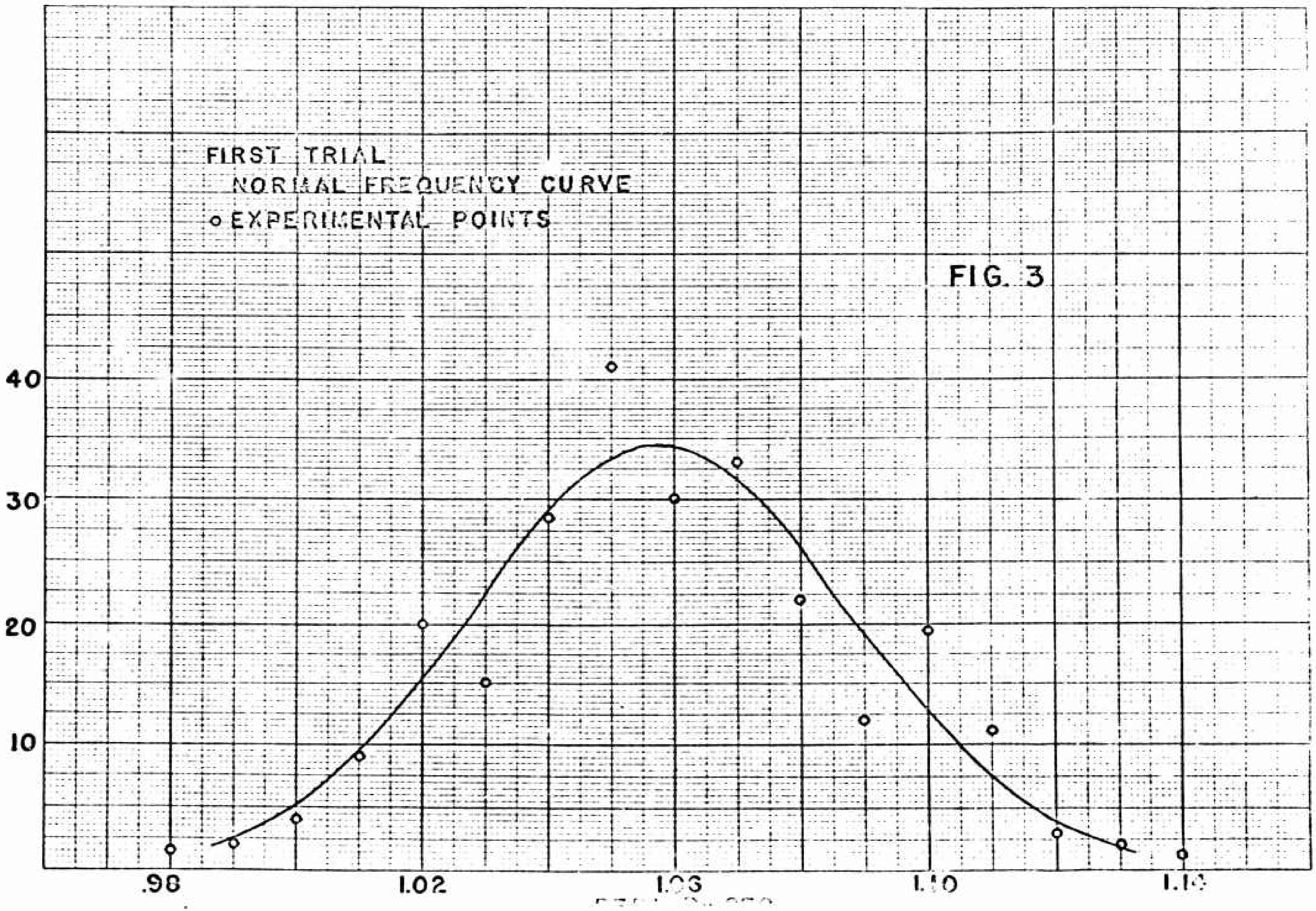

FIRST TRIAL
NORMAL FREQUENCY CURVE
o EXPERIMENTAL POINTS
40
30
20
10
.98
1.02
1.10

FIG. 3

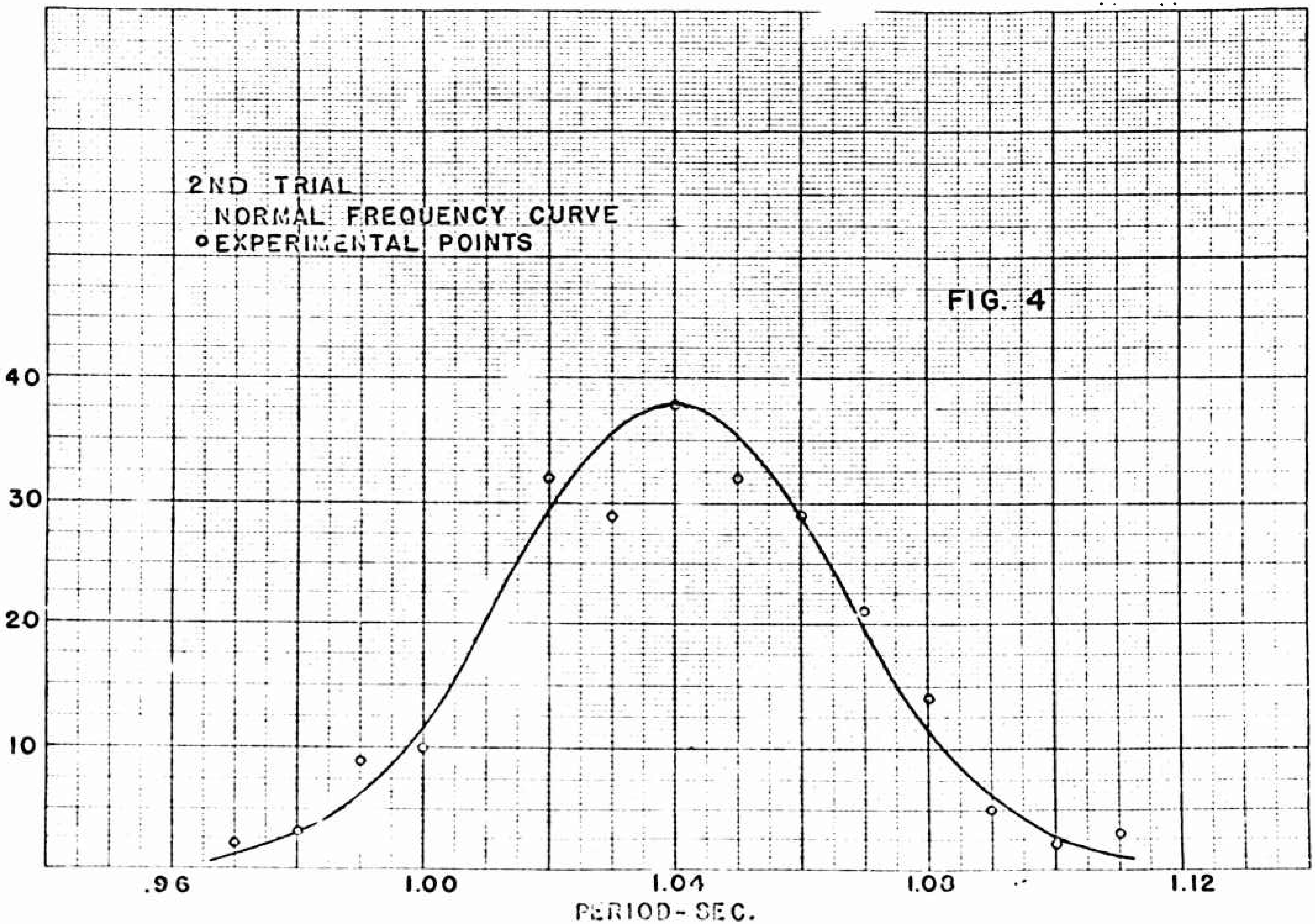

2ND TRIAL
NORMAL FREQUENCY CURVE
o EXPERIMENTAL POINTS
40
30
20
10
.96
1.00
1.04
1.08
1.12
PERIOD - SEC.

FIG. 4

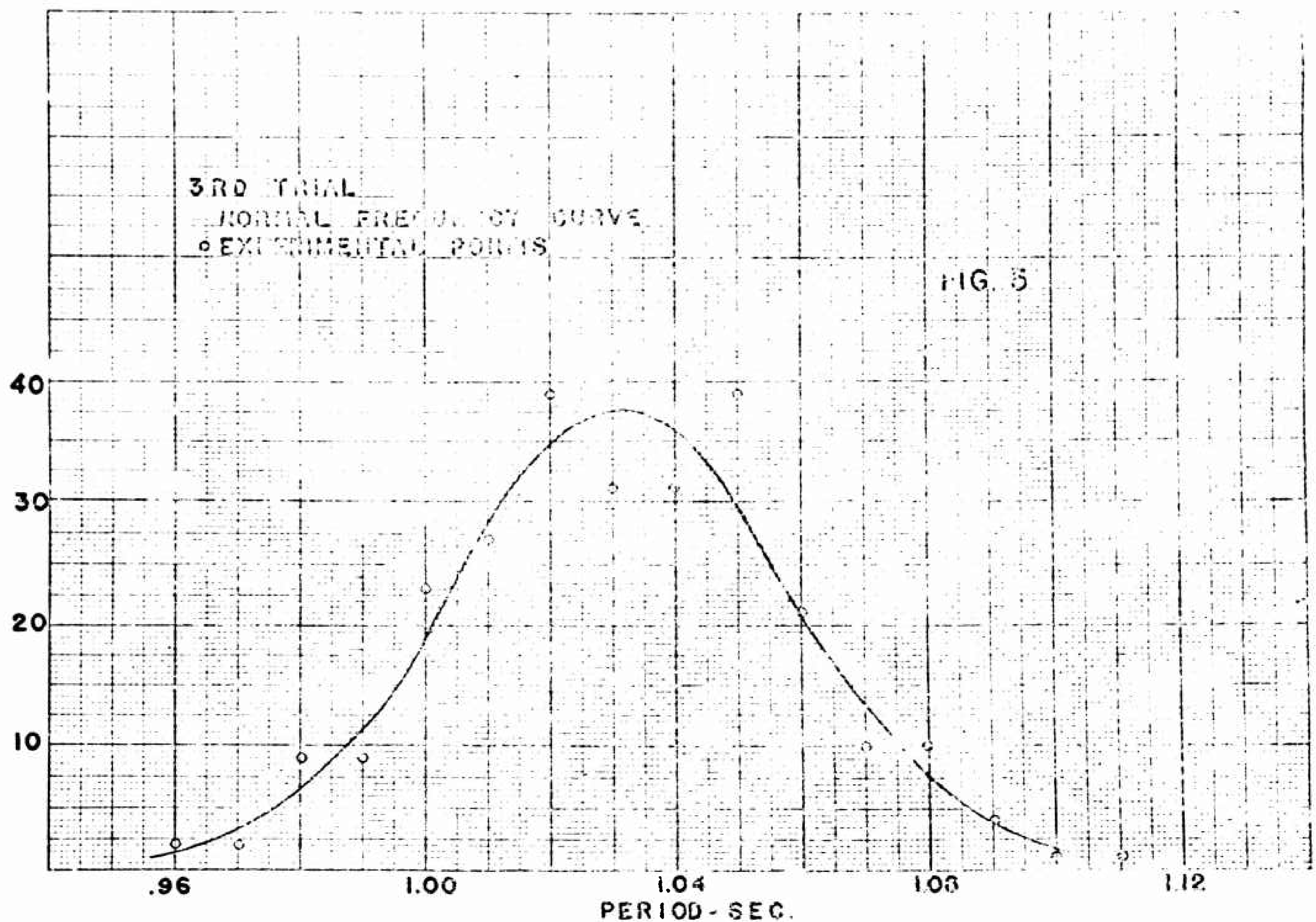


FIG. 5

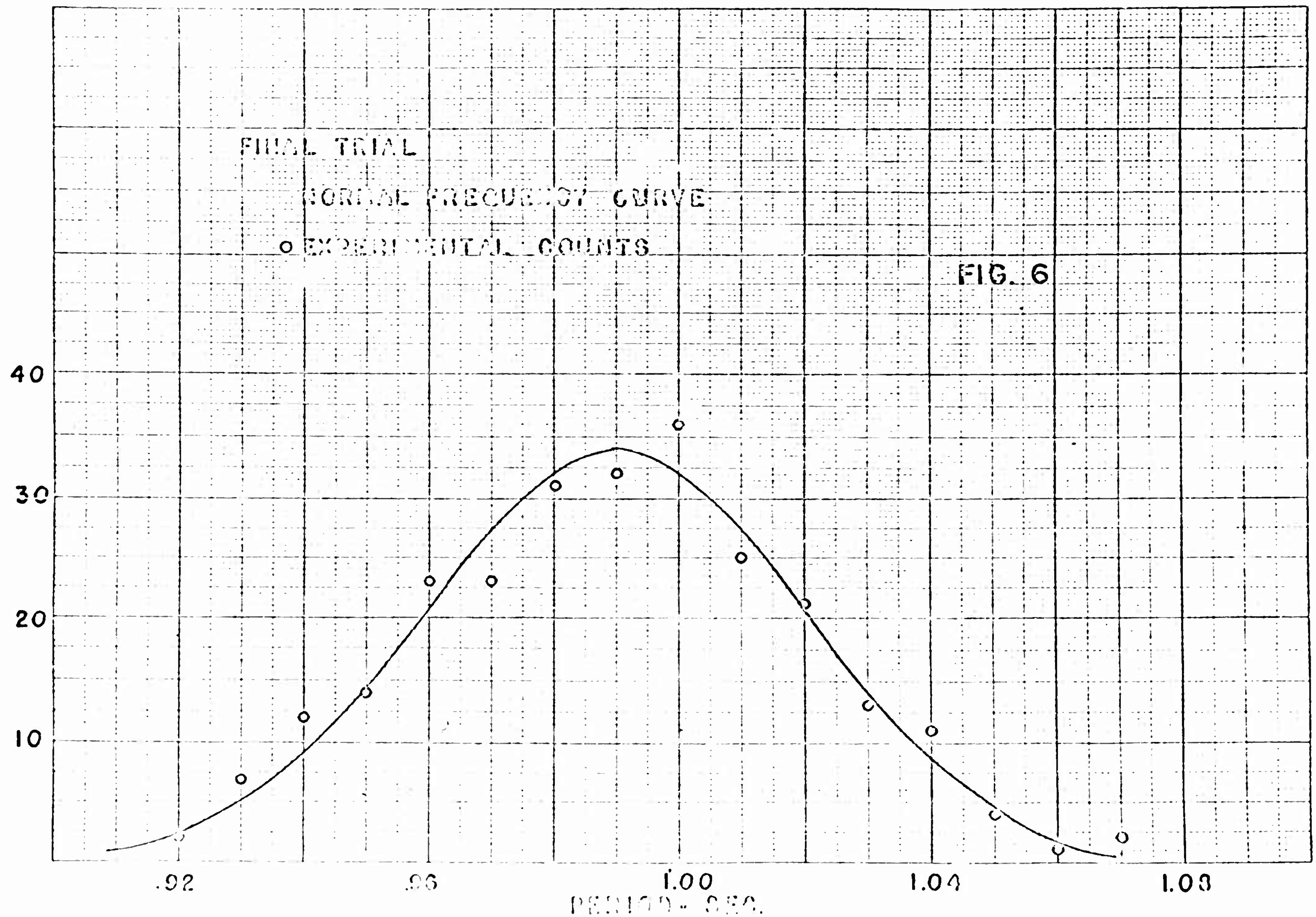

FINAL TRIAL
NORMAL FREQUENCY CURVE
o EXPERIMENTAL COUNTS
40
30
20
10
.92
.96
1.00
1.04
1.08
PERIOD - SEC.

FIG. 6

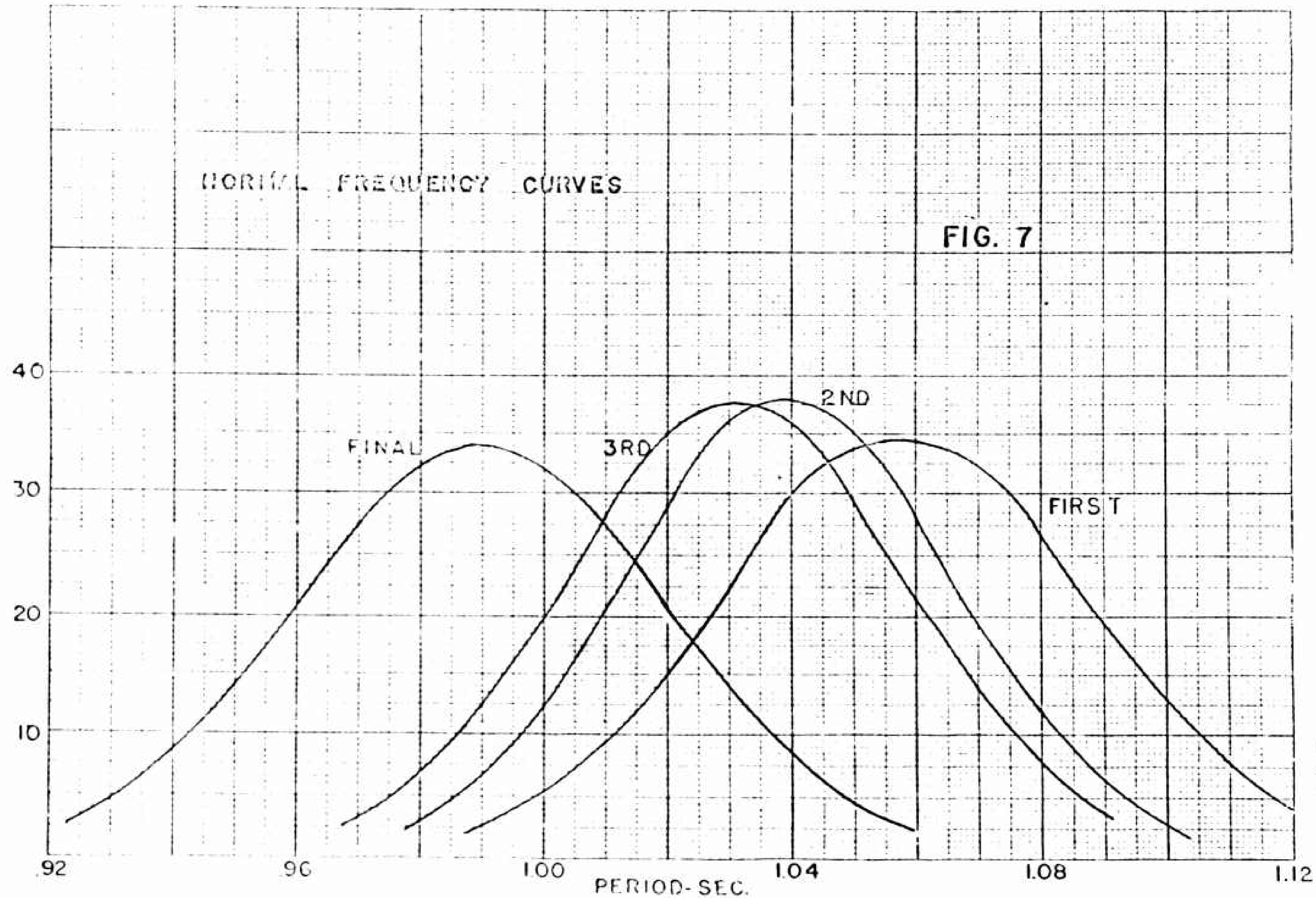

NORMAL FREQUENCY CURVES
FINAL
3RD
2ND
FIRST
40
30
20
10
.92
.96
1.00
1.04
1.08
1.12
PERIOD-SEC.

FIG. 7

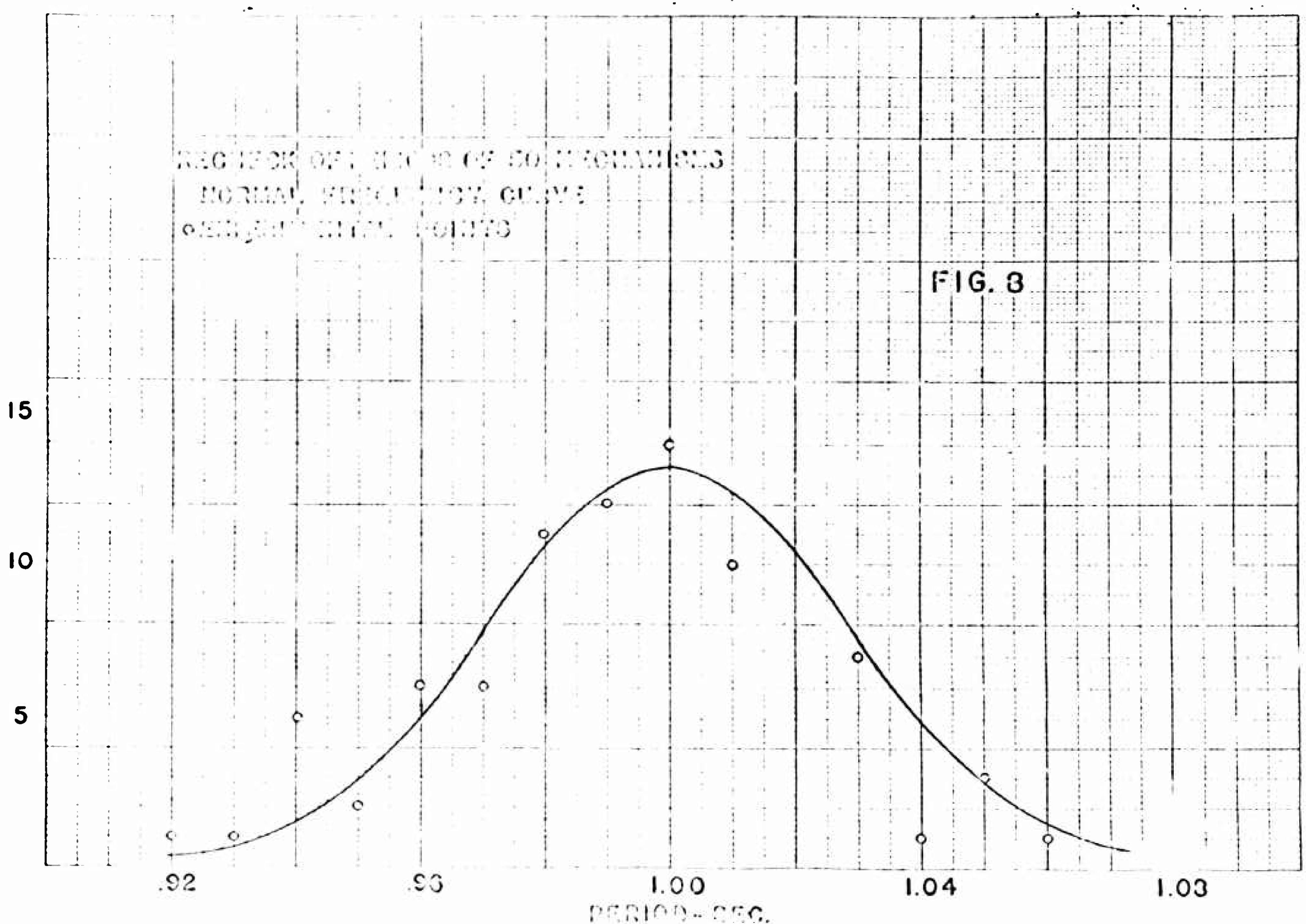


FIG. 3

The result of these statistical studies seemsto establish first that some 85% of all mechanisms will lie within ± 5% of the nominal value of the period of the mechanism. This statement is made with the understanding that the mean value established by the normal frequency curve was nearer .99 sec. than 1 sec., but that an interval of .01 sec. is not physically significant. Upon this basis the above statement seems justified. Secondly the running time of a mechanism is determined partially by the number of times it has been run previously, and there is a decrease of some .07 sec. as a mechanism is run in thoroughly. Finally, the period of even a thoroughly run in mechanism usually increases some .02 sec. or more when it is stored for even a short period of time, a day or so. Unfortunately then, we find not only the expected spread or lack of uniformity in the periods, but also a dependence of these periods upon the past history of the mechanism.

III. EFFECT OF MECHANISM POSITION ON PERIOD.

In the schematic diagram of Fig. 1, the position of the shafts is perpendicular to the paper. The two supporting brass plates, which act as a casing for the mechanism, would be parallel to the paper. Holes drilled in these plates serve to support the shafts.

When the period of the mechanism is determined there are four positions in which it may be placed. They can be described as follows:

1. Plates horizontal, inertia disc above verge.
2. Plates horizontal, inertia disc below verge.
3. Plates vertical, verge points down.
4. Plates vertical, verge points up.

Periods were determined for 50 mechanisms, each taken in all four positions. In some 35 cases, the time associated with positions 1 or 2 is larger than the time measured in positions 3 or 4. However, the periods for positions 1 and 2 are not necessarily equal, nor are those for positions 3 and 4. One must not infer that there is a clear and well defined difference in these data. One does note however, that in a horizontal position the mechanism period is generally greater than that for a vertical position.

The maximum variation among the periods for all four positions for one mechanism was .07 sec. occurring for but one of the fifty mechanisms. For at least 40 of the mechanisms the variation was .04 sec. or less. Except for some extreme cases, then, the period did not change greatly with position of mechanism. Such changes as did occur followed no particular pattern of behaviour from one position to another except for the general observation noted above. This may be explained as follows. In position 1 or 2, the plates horizontal, all the elements of the mechanism, verge, gears etc. would tend to run with the shoulder on the shafts rubbing on the plates. In positions 3 and 4 the shafts are horizontal and when in motion these shafts rest on the edge of the holes in the plate supporting them. In the first case a greater area of surface is in contact, so that there is a greater chance of frictional resistance due to burrs and irregularities in the greater surface area. Study of these shafts under a low power microscope indicates clearly that the shoulders of the shafts, which are the contact areas in the first case, are much less smooth then the cylindrical surfaces of the shafts which are the contact areas in the second case. Additionally, even though the frictional forces were the same in either case, the effective lever arm of the resistive torque in the first case is greater than for the second. This also would contribute to the observed result.

It may be emphasized in closing this section that position is a factor to be recognized. The nominal delay time of a mechanism may be changed by 2% to 5% according to the position in which it is run.

IV. THE EFFECT OF INDIVIDUAL COMPONENTS.

It was considered advisable to attempt to determine how certain individual components of the mechanism affected the delay time. A mechanism was first disassembled and rebuilt in such a way that the spring, the starwheel, or the verge, any one, was removable. The photographs of Fig. 9 show this test mechanism. In this way a whole series of verges, for instance could be tested under as nearly identical conditions as possible. Because this data is of some importance it is included in a table on the following page. Actually there are two sets of data included in the table. In the first, the wheel, verge, and spring of mechanism 130 were used as reference elements in the test mechanism. As they began to show wear, they were replaced (in the second half of the table) by the elements of mechanism 92. The mechanism numbers have no significance other than a means of identification.

No particular importance should be attached to any one value of the period appearing in the table, but certain striking general conclusions are at once evident. First, the individual springs must be very nearly the same in the torque they deliver to the starwheel, since the variation in periods from one spring to another is very small, in general about .03 sec. for either set of data. It is to be remembered, of course, that the whole mechanical system including drive wheel shaft, washers, intermediate gears, starwheel and verge is identical for each spring. Hence all frictional effects (except the rubbing of one spring coil against another) are, we hope, the same regardless of the spring used. We may conclude with some assurance that the variation in individual springs may indeed account for some of the observed variation in mechanism time, but is not, probably, the major factor.

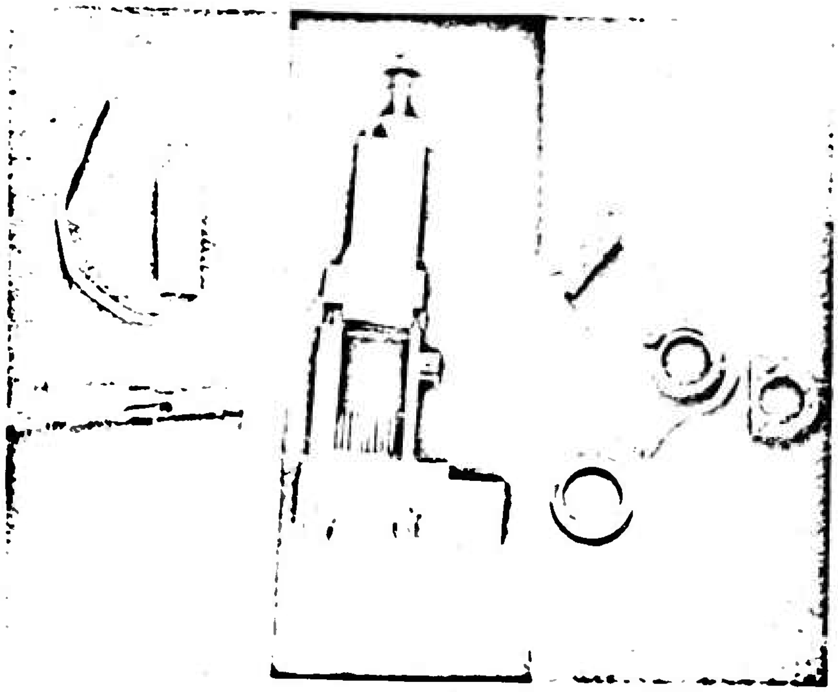
Next consider the results included in the column headed "Verge-wheel periods". For these data, the verge-wheel combination was used, that is, we placed in the test apparatus both the verge and wheel from the same mechanism. Here we find a large variation in the periods, of magnitude approximately .13 sec. This variation approaches in magnitude the variations observed in the large sample of 275 mechanisms. Trying the verge and wheel separately, it becomes evident that it is the verge which is primarily responsible for this variation. The variation in period introduced by the wheel is some .03 sec. There is excellent correlation between verge periods and verge-wheel periods.

It must be noted, however, that there is no correlation between the periods recorded orginally for the various mechanisms before they were disassembled and any of the times given in the data table under discussion. Quite clearly, the friction present in the various rubbing surfaces of any given mechanism is of utmost importance in determining the period.

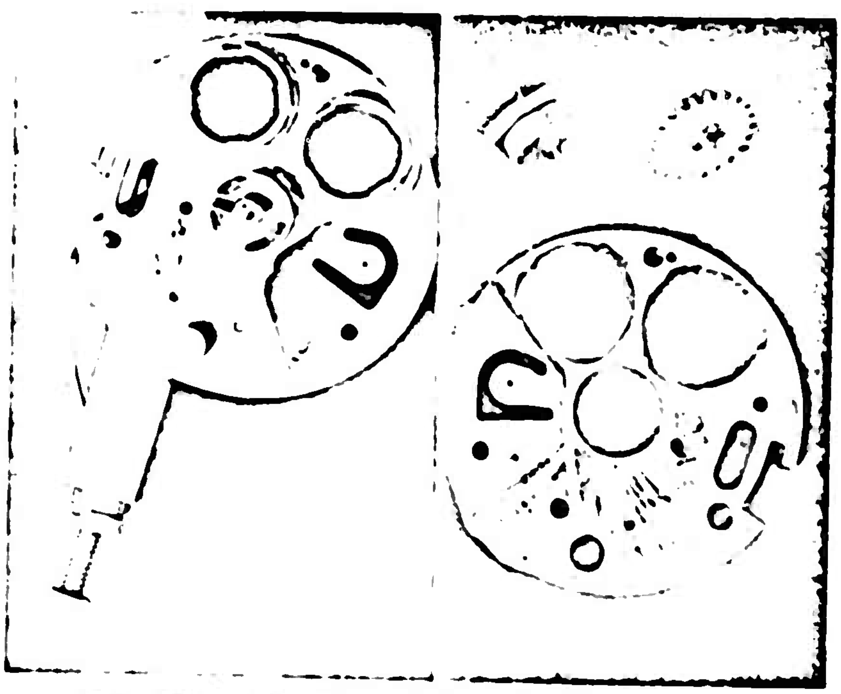
The end result of the observations recorded above is that it would be worth examining a number of verges carefully with a view of determining the factor or factors which cause the great variations in period. By the same token, it seems unnecessary to attempt to study individual springs or starwheels, since their effect is so small.

	Element Number	Spring	Verge-Wheel	Wheel	Verge
		Period	Period	Period	Period
Spring, Verge, Wheel of mechanism 130 were used as the reference elements for these data.	130	.98	.98	.96	.97
	122	.98	.87	.96	.88
	121	.98	.94	.93	.95
	129	.96	.99	.93	1.00
	117	.98	.96	.95	.96
	116	.97	.94	.95	.93
	97	.97	1.00	.95	1.00
	108	.97	1.00	.96	1.00
	115	.97	1.00	.94	1.01
	92	.99	.95	.94	.98
	130	.97	.98	.96	.96
Spring, Verge, Wheel of mechanism 92 were used as the reference elements for these data.	92	.97	.95	.96	.99
	95	.95	.97	.96	.97
	96	.95	.99	.98	.96
	99	.96	.92	.95	.93
	100	.97	.96	.97	.96
	101	.96	.90	.91	.95
	102	.96	.98	.97	.97
	103	.96	.98	.98	.96
	104	.96	.91	.94	.93
	105	.98	.97	.96	.96
	106	1.00	.98	.96	.97
	92	.97	.95	.95	.97

Explanation of table: The first column is the number of the particular element (wheel, verge, spring) being tested. The 2nd column gives the periods for each spring tested, it being understood that the reference wheel and verge were not changed as different springs were used. Analogous statements hold for the other columns.



TEST MECHANISM DISASSEMBLED IN PREPARATION
FOR CHANGING SPRING



TEST MECHANISM DISASSEMBLED IN PREPARATION
FOR CHANGING VERGE,STARWHEEL,OR BOTH

Figure 9.

V. DEPENDENCE OF PERIOD UPON VERGE CHARACTERISTICS.

The most obvious characteristic of the verge which might account for the time variations of the preceding paragraph might be the moment of inertia. This is, of course, a small quantity, but it can be measured. It is small enough so that the measurements one can make are not very precise. Now if the moment of inertia varies from verge to verge, it does so because of one of two things; either the mass changes, or the dimensions of the verge change. Actually one would expect these to be mutually dependent.

Ten verges, chosen from among those used in the experiment described in section IV, were weighed on an analytical balance. Their masses were found to vary about 3% from one extreme to the other. It does not follow, of course, that there is the same variation in moment of inertia, for nothing is known about the distribution of this mass variation. There is no doubt that individual verges do vary in geometrical dimensions from one to the other and this will most certainly affect the distribution of mass. Unfortunately many geometrical measurements on the verge are difficult to make, because of the rounding of supposedly sharp corners and because the thickness of the verge is not uniform after stamping.

By using a small torsion pendulum the moments of nine different verge-inertia disc combinations were measured. These moments were found to lie between the values .0341 gm-cm^2 and .0367 gm-cm^2 as extremes, a difference of some 7%. The method of measurement itself is not too precise when dealing with such small quantities, so that not all of this difference is perhaps real. Except for the two extreme values given above, the variation did not exceed 3%. Since the period of the mechanism has been shown theoretically to depend roughly upon the 0.5 power of the moment of inertia of the verge, we may probably conclude that a variation in verge moment is not among the more important causes of variation in period.

As a matter of interest it was found that filing away some of the material at the end of the inertia disc of the verge shaft did not appreciably change the period.

Since measurements of the various verge dimensions did vary from one to the other, it is important to ascertain which of these dimensions is critical in the determination of the period. Reference to the theory of Reports 1 and 2 on this same problem show that it is the leading collision which always affects the motion of the wheel most strongly. It might be expected that any geometrical variation which would vary the position of leading collision would affect the period. On the other hand changes in the dimensions affecting the trailing pallet face would have a much smaller result on the period. This is amply born out in experiment. If one mills off one to two mils (.002 inches) of surface A (trailing pallet) there is no observable change in the period. Milling off one to two mils of surface

B (leading pallet), on the other hand, did affect the period radically in every case tried. We then attempted to measure the distance X_o (see Fig. 10), which should be an indication, poor though it probably is, of the position of face B in the 15 verges measured. A variation of X_o from .097 inches to .102 inches was found. Specifications call for a distance of .097 inches in this dimension. In all verges examined, $X_o > X_o'$, and the sum $X_o + X_o'$ varied from .192 inches to .197 inches as against a specified dimension of .194 inches. Even under a low power microscope these measurements are difficult to make, but we feel certain that a real variation in X_o does exist and that this in turn contributes greatly to the observed spread of periods.

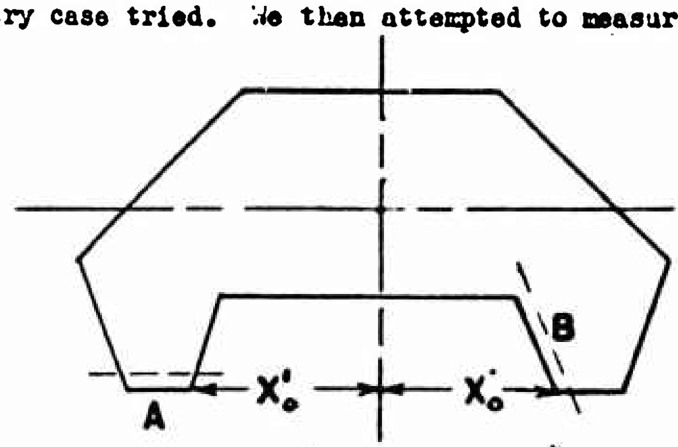


FIG. 10

No other change in verge dimensions could be found which effectively changed the period, including a rounding off of the verge corners.

VI. CENTER TO CENTER DISTANCE.

A complete theoretical discussion of the effect of k on the period is given in our previous report, where k is the distance from center of verge shaft to center of starwheel shaft. It has been established theoretically that as k varies by a small amount on either side of the specified value, the period will vary linearly. More precisely it is found that an increase or decrease of k by 2 mils (.002 inches) results in a decrease or increase of the period by some 8%. Clearly this dimension will be important in determining the period. Sixty mechanisms were studied and in each case the static center to center distance was measured. By static distance we mean the distance as determined by the shaft bearing holes drilled in the plates making up the case. In about 65% of these mechanisms a correlation between period and center distance was found. Actually such a correlation is not basically important, for in this as in all cases, so many physical factors enter the problem at the same time that the particular factor being studied is probably well masked. That even a 65% correlation exists, indicates the apparent importance of this effect of center to center distance. The variation of k was a maximum of 2 mils above and below the specified value of .222 inches.

Now examination shows that the diameter of the holes in the plates which carry the shafts of the verge and starwheel are considerably larger than those of the shafts themselves. When the mechanism is operating, the position of the shafts change and each tends to ride over on one side of its hole. It happens that both shafts move in the same direction in their respective holes so that the kinetic center to center distance is not essentially different than that measured statically. This variation in center to center distance does certainly affect the period, and is probably one of the more important factors.

VII. TORQUE MEASUREMENTS.

Before the results discussed in section IV were obtained, a great deal of effort had been put into an attempt to measure the torque exerted on the starwheel. This torque is, of course, transmitted from the spring through the driving and intermediate gears to the starwheel. Despite some contradictory evidence, we feel that nearly all the friction encountered in this apparatus is in this gear train and spring shaft assembly, and that friction has little affect in the verge-starwheel combination. For this reason, an accurate measurement of the dynamic torque delivered to the starwheel would be very informative. Unfortunately we have not been able to accomplish this, despite several different approaches to the problem.

Some measurements of static torque were made but these were not very informative. They simply showed that all springs were nearly identical. Our later work described in section IV certainly corroborates this statement. It is certain, finally, that there is friction in the apparatus. Whether its magnitude remains essentially constant or varies greatly from one mechanism to another, we do not know, although the second alternative is by far the most likely.

VIII. THE EFFECT OF SURFACE CONDITIONS.

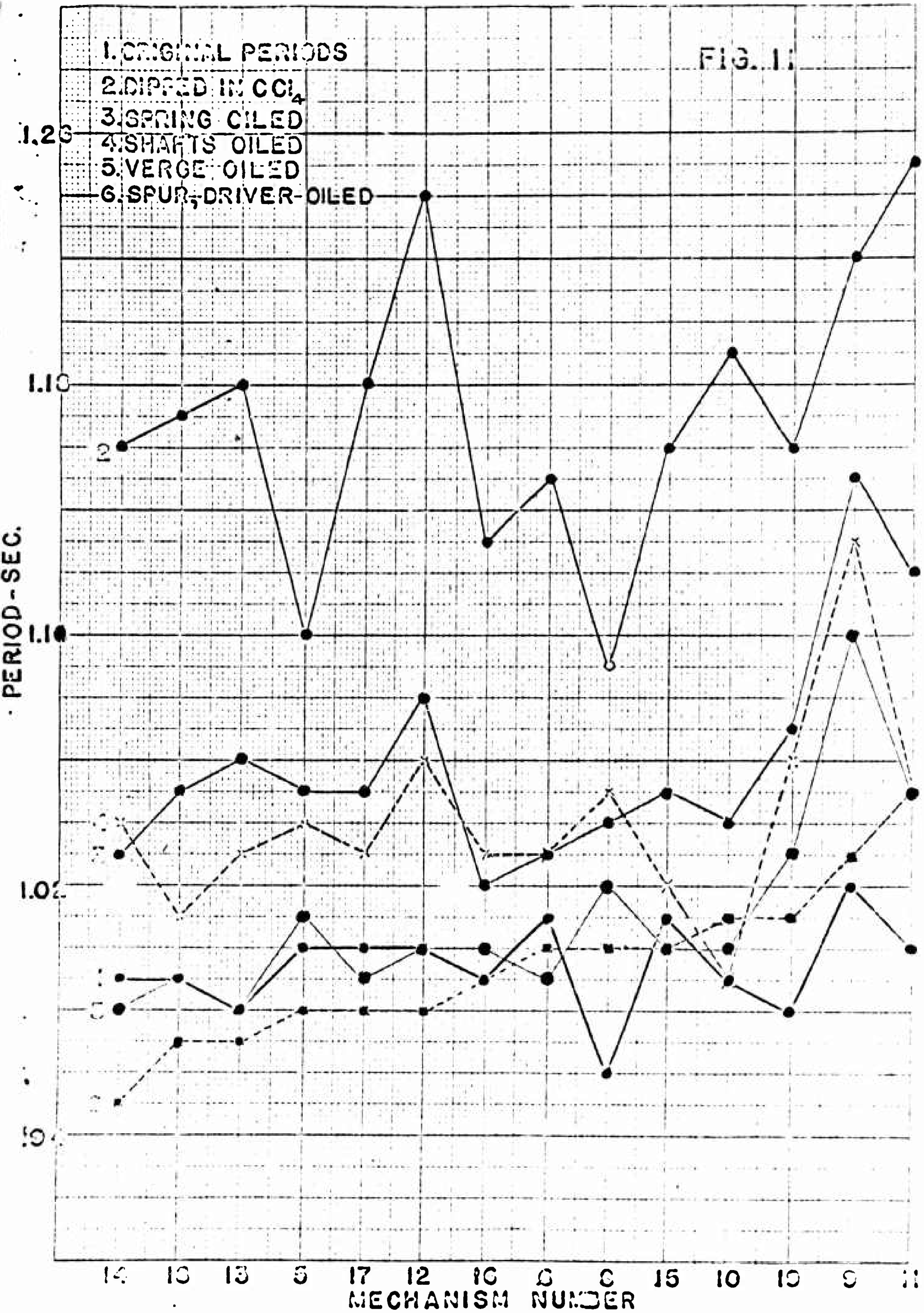
As in any physical situation involving friction, the condition of the contact surfaces can play an important role in the behaviour. The following simple experiment was performed on some 14 mechanisms, each mechanism having been "run in" and timed as described in section II. On the graph called Fig. 11, there is plotted a curve 1, which represents these times. It is to be clearly understood that this curve has no physical significance, nor does any other curve drawn on the graph. Their sole purpose is to enable the reader to follow easily the array of points representing the mechanism periods under the various physical conditions specified. The mechanism numbers used as abscissas are as before simply means of identification.

Each mechanism was now thoroughly washed in carbon tetrachloride and retimed. The results are given in curve 2. Before the periods of curve 2 were measured the mechanisms were thoroughly dried. Whatever the physical effect produced by the CCl_4, clearly frictional effects were intensified. No serious work on this actual effect was done, but one can imagine that either one of two things, or both, are operative. There may be a surface film of oil or grease which is removed by the CCl_4, or it may be that CCl_4 reacts chemically with the surface or the plating on the surface.

Now by selective lubrication, we attempted to determine in what parts of the mechanism, friction was most important. First the spring itself was oiled with Nye Watch Oil. Curve 3 shows how the period decreased for all mechanisms. In the oiling of the spring, it was not possible to keep oil away from the drive gear shaft. Some oil certainly found its way onto the drive gear shaft bearings and up under the washers associated with them. Next all other shafts were oiled with results shown in curve 4. Such differences as do seem to exist are with one or two exceptions negligible, considering curves 3 and 4.

The verge surfaces were then oiled and of course, after one running, the starwheel surfaces had also become oiled. Although there is here also some uncertainty, curve 5 seems to indicate that oiling these surfaces makes a real difference in period. Finally, the meshing teeth of intermediate gear pinion and drive wheel were oiled. The tightest fit between teeth occurs at this point. Here again the differences in period do not seem to be significant, for most mechanisms.

The evident conclusion from these data is that friction is most important in the springs, and secondly that oiling the verge surfaces heavily decreases the period. As far as the spring is concerned, the friction is most probably localized between the turns and also at the washer-case interfaces on the spring shaft, most probably the latter. To test the validity of this assumption, the periods associated with four different springs were measured in the test mechanism described in section IV, both before and after the springs themselves were dipped in CCl_4. This cleaning produces a marked effect in the appearance of the spring indicating a change in surface conditions. Here, we found the contradictory result that the periods decreased slightly as the result of dipping. The basic reason for this unexpected result is not


1. ORIGINAL PERIODS
2. DIPPED IN CCl_4
3. SPRING OILED
4. SHAFTS OILED
5. VERGE OILED
6. SPUR-DRIVER-OILED
FIG. 11
PERIOD - SEC.
MECHANISM NUMBER
14
13
17
12
15
10
9

known. The friction between turns of the spring itself may not be due entirely to the surface condition but to dirt, dust, etc.

One last observation might be noted. Measuring the periods (in the test mechanism) associated with several verges before and after cleaning in CCl_4 revealed no significant change in these periods.

VIII. MISCELLANEOUS OBSERVATIONS.

(A) Separation of Casing Plates.

An important factor in the free running or jamming of the mechanism is the orientation and spacing of the two plates which make up the casing. In mounting these mechanisms in the timer, some three of them jammed because the plates were spread or rotated slightly. Whatever method of mounting is used, a slight binding is enough to jam the gears. One can pinch the casing plates between his fingers slightly and see this happen. The shoulders on the starwheel shaft being caught between plates, the resulting frictional torque exerted on the starwheel easily stops its motion.

(B) Loose Gears and Verges.

In a few instances, it was found that after running the mechanism, a gear or the verge had worked loose on its shaft. This always allows the mechanism to "run away". In practically all cases, however, the gears and verges are very tightly fastened to their respective shafts.

(C) Inaccurate Drive Gears.

There are some slight differences in the drive gear-intermediate pinion combination in the mechanisms. In some cases, the drive gear, when the spring is cocked, must turn through a quarter to a third of a tooth spacing further than normal before slipping free. Since the angular travel of the drive gear is about 15 tooth spaces this can make a difference in period of some 2%.

(D) Physical Smoothness of Components.

It was noted that specifications require that the pallet faces should be finished smooth, while the rest of the verge is left as it comes from the stamping process. Under a low power microscope, one can observe the tool marks, which form little ridges running across the face, normal to the flat sides of the verge. First, several verges were ground until the pallet faces were quite smooth. This produced no appreciable change in period. Next, the pallet faces were deeply scored and roughened. This also caused no significant change in period.

The shafts were observed to be remarkably smooth and free from burrs. The shoulders on these shafts which bear on the casing plates appeared to have been filed or otherwise finished to remove any burrs left after turning. The diameters of the shafts are considerably less than those of the bearing holes in which they rest. Both shoulders and holes for verge and starwheel bearings were chamfered, with no appreciable change in periods. Then shoulders, shafts, and bearing holes were deeply scored and filed. As long as the shaft was a loose fit in the holes, the periods did not change. It does not appear that the physical smoothness of shafts, shoulders, or bearing holes is of particular importance.

(E) Other Mechanisms.

We had available for experimentation, fifteen 1/2 sec. mechanisms. We put these through many of the same tests described in the preceding sections. The results for these 1/2 sec. mechanisms were in general agreement with those recorded above.

In addition to these mechanisms, we experimented briefly with one 5 sec. mechanism. Such results as were obtained were quite different from those found for the 1/2 sec. mechanisms. In fact, in some situations, there were directly contradictory results. Of course, one should remember that the 5 sec. mechanism has one extra gear and pinion in the train but otherwise is practically the same. It is clear on examination and comparison that the casing plates are also designed somewhat differently. We offer no explanation for the 5 sec. mechanism behaviour, other than the fact that friction has a relatively greater effect due to the decreased torque on the starwheel.

IX. CONCLUSION.

We can state the most important facts derived from this study as follows:

(1) All mechanisms approach a constant running rate or period as they are run repeatedly. At any time, a mechanism has been allowed to rest for some hours or days, its period is large when first rerun and then decreases to the constant period above. There is an 8% variation above and below the most popular value of the period.

(2) The period of the mechanism changes with the position in which it is held when running.

(3) Of the individual components of the mechanism, the verge introduces the greatest variation in period. This is mostly caused by variations in certain geometrical dimensions and very little by friction or rough surfaces.

(4) The center-to-center distance, verge shaft to starwheel shaft, is an important factor in the variations of period and can of itself introduce a 7% variation.

(5) The torque delivered at the starwheel may vary greatly because of different frictional effects from mechanism to mechanism. The torques produced by individual springs are very nearly uniform.

(6) Surface roughness or shape of shafts and bearing holes, as well as pallet faces do not affect the periods significantly. The cleaning or corrosion of the sliding surfaces does affect the period greatly.